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IMPACT OF PRECOAT STRUCTURE ON TOPCOAT PERFORMANCE IN COATED BOARD

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ABSTRACT

Multiple coatings are often employed to give a smooth, highly opaque and even surface on coated board which is suitable for high quality printing. The first coating applied generally contains coarser pigments which give high bulk and good coverage of the fibres. The topcoat is often designed to have finer pigments in order to obtain the required gloss, optical properties and end functionality (laser marking and printing). As well as the impact of the pigment choice in the formulation, the method of application of the coating and the rate that it dries also have a significant influence on the resulting topography and pore structure. The binders, thickeners and additives in the coating formulation will control the rate of water loss during the coating process and this determines the runnability of the coating layer on the board machine as well as its final structure.

This publication is the first in a series of 3 which explore factors which impact the structure of the precoat and its subsequent influence on the topcoat. In this work the same basepaper, pigment and latex binder systems are used throughout and the variables studied are the speed of the coating drying, the weight % solids of the coating colour applied to the base and finally the impact of adding thickener to the precoat. Mercury porosimetry and stain length tests were used to probe the bulk and surface porosity of the layers respectively and in each case the impact on the porosity of the precoat alone and the final top coated board were assessed. A comparison of the bulk porosity of coatings applied onto porous basepaper and onto non porous plastic was also made to determine the impact of dewatering on the dried layer structure. SIMS sectioning and labelling of the precoat and topcoat with markers also allowed assessment of movement of water and starch within the coated board.

The work has proved that the pore structure of the precoat is very dependent upon the substrate to which it has been applied (porous or non-porous), the % solids content and the amount of thickener added as well as the speed of drying. These differences then follow through in influencing the structure of the final topcoat. The work will help provide levers for the paper and board producer to be able to optimise his whole coating formulation.

Keywords: coated board, precoat, topcoat, porosity, dewatering

1. INTRODUCTION

A coated paper or board is composed of the fibrous layer which is encapsulated (top and bottom) by a porous coating layer consisting of pigment, binder and air. It has been well established that the porosity between particles in the dried coating layer often has a larger impact on the print performance than the solid component in the coating layer and therefore many publications concern the use of pigments & binders required to design the coating pore structure. However less has been discussed comparing the impact of drying and solids content on the final product, especially with reference to the precoat or first coating applied to the board. After application of the coating a large amount of binder/water migration into the base paper will leave the top of the coating more vulnerable to the physical demands of printing processes.

The drying & coating consolidation process can be thought to occur in three phases:- First, the coating colour dries until it reaches the first critical concentration; a 3D fluid-filled network is formed and particle motion is greatly restricted. In the second phase, the water-air interfaces recede into the surface pores, forming capillary elements and creating a differential capillary pressure that causes shrinkage of the network, this continues until the second critical concentration is reached; the structure is rigid. The capillaries empty until drying is completed ¹. A slow dry will lengthen the time before the FCC/SCC are reached- water will migrate downwards further than a fast dry and therefore the fines and binder have more chance to move downwards into the base leaving a higher porosity coating. However there is also a competing effect- a slow drying and consolidation time will allow time for a broad particle size distribution pigment to rearrange and the particles to pack closely together – potentially decreasing the pore size and volume. There is a significant amount of published work that indicates the impact of pigment choice in a coated layer ^{2,3}, in terms of fluid imbibition ⁴, optical performance, and

printability^{5,6,7,8}. The importance of the binder choice and level has also been widely discussed within the paper community⁹. A harder latex (higher Tg) will cause less shrinkage of the layer during the drying phase resulting in a higher porosity coating layer¹⁰. Finer pigment particles have a higher surface area and therefore a higher binder demand¹¹ and those with a narrow PSD also pack more openly giving a higher porosity and lower strength¹². This publication explores the impact of coating colour solids content, drying rate after application and the influence of thickener addition on the coating structure, using the same pigment, basepaper and binder system. A subsequent publication will address the differences observed with pigment selection in the precoat – incorporating different pigment types, particle size distributions and shapes and a further publication will focus on various binder types and levels.

2. METHODS

In this work the same precoat coating formulation was applied to a woodfree base and then consolidated immediately through fast drying on a high speed blade coater (Helicoater™) using IR and air dryers and slowly by application of the colour to the same base using a bench top coater and then standing for several seconds before oven drying. Portions of the coating were also dried on a non-porous base, to determine the structure of the coating with no dewatering occurring, only evaporation drying. The precoat was analysed to determine their porosity using air flow methods, stain length and mercury porosimetry. A fine GCC topcoat was then applied to both precoat using a benchtop coater, and the final coatings re analysed in terms of their porosity and print quality.

Secondary ion mass spectrometry (SIMS) in surface mapping mode was utilized to determine the spatial distribution of ion fragments within the sectioned paper coatings. In this case easily detectable “probe salts” were added in low concentrations to the pre- and top coat coating colours, so that the movement of the fluid phase could be determined after the coatings had been dried with respect to the basepaper.

2.1 Materials

The following precoat formulation was used: 100pph GCC 60, 4pph low molecular/low viscosity weight thermally modified corn starch, 6pph standard SBR Latex, synthetic thickener, CsCl₂ and KBr markers. The PC was screened at 53µm before coating onto a woodfree base (118 gsm, PPS 1000 kPa = 5.7µm). Colours were coated on the Helicoater with the short dwell head at 800 m/min and the benchtop rod coater.

Table 1. Coating Parameters

| | Drying speed | Solids wt. % | Viscosity (Brookfield 100 rpm / mPa.s) |
|---------------------------|--------------|--------------|--|
| Helicoater | Fast | 66.5 | 120 |
| Helicoater | Fast | 63 | 85 |
| Helicoater with thickener | Fast | 63 | 1000 |
| Benchtop rod coater | Slow | 63 | 85 |

Different drying methods were used to compare immobilisation times.

- Helicoated samples dried using hot air and IR, labelled “FAST DRY”
- Bench top coated then left to air dry for 120s before being placed in an oven set at ~82°C for 3 minutes, labelled “SLOW DRY”
- Portions of the coating colours were also applied to a non-porous surface and dried. This was to determine the “intrinsic” porosity of the coating layer with no impact of dewatering and loss of components into the basepaper.

The topcoat consisted of an ultrafine GCC (d₅₀ = 0.25 µm) combined with 9 pph of standard SBR latex. The coatings were applied using a bench-top rod coater onto the precoat base with a target coat weight of 12 gsm at 61% solids. All the coated papers were conditioned at 50% relative humidity and 23°C for at least 24 hours before laboratory paper testing was performed. In order to determine the position of the binders and the depth of penetration of the water phase into the base before drying; the coating colours were labelled with salts which were specifically selected to be easily detectable in Secondary Ion Mass Spectrometry (SIMS). CsCl₂

was added to the precoat (this soluble salt moves with the water phase), iodine was used to track the position of the starch and KBr was used to track the water and binder movement from the topcoat.

2.2 Methods

The coated papers were assessed for their optical properties using an Elrepho Spectrophotometer (D65 without UV). Porosity was measured in units of Gurley seconds using a Messmer-Büchel Parker Print-Surf (dual head). A Gurley second is defined, by test method TAPPI/ANSI T 460 om-11, as the time taken for 100 cm³ to pass through one square inch of paper whilst under a pressure differential of 1.22 kPa. Therefore a low value in Gurley seconds translates to a high porosity. Mercury porosimetry was used for more detailed pore volume and pore size distribution data. This was measured using Pascal 140 and Pascal 240 porosimeters from Thermo Scientific. The dry pick strength of the coated papers was measured using an AIC2-5 unit (IGT). The unit was run in accelerating mode up to a maximum velocity of 6 ms⁻¹. 1 cm³ of a standard pick oil of viscosity 17 Pa.s was applied and the print was assessed visually using low angle illumination to assess the speed and mode of failure. Measurements were made in triplicate. The absorbency of the coatings was measured using a stain length test on the IGT printer apparatus. A controlled volume drop of dibutylphthalate, with Sudan red IV dye was applied from the syringe to this disk, and then transferred to the sample through a nip on the IGT press at a speed of 0.5 m/s. Measurements were made in triplicate. The length of the stain gave an indication the porosity of the coating. An imaging reflectometer was used to determine surface porosity by refractive index (RI) measurement using polarised light at two wavelengths ⁽¹³⁾. The dewatering speed was determined using the AA GWR dewatering apparatus. 10 ml colour is placed in the chamber and a pressure of 1 bar applied for 60 seconds. The fluid phase passes through a 47mm, 5µm cyclopore membrane into a thick filter paper. The weight of the filter paper is weighed before and after colour application to determine the amount of water lost. Secondary ion mass spectrometry has used to determine the penetration of the starch within paper layer previously ¹⁴ and to obtain good spatial resolution on the distribution of ions within a printed paper section. The magnetic sector SIMS instrument used in this work was constructed within the Interface Analysis Centre at Bristol University. The main components are a focused gallium ion gun (FEI SD gallium LMIS EVA focusing column), a double-focusing magnetic sector mass analyser (Vacuum Generators model 7035) and a Thornley-Everhard electron detector. The ions produced by bombardment with the gallium ion beam are accelerated through an ion extraction lens and into the mass spectrometer using a sample potential of 4 kV. The ions then pass through an electrostatic energy filter, a magnetic mass filter, and a slit before reaching a channeltron detector. The spatial resolution is determined by the diameter of the ion beam, and was approximately 300 nm in this work. The magnetic sector SIMS technique was used to collect images of cross sections of coated papers. The substrates were embedded in epoxy resin (under a vacuum and raised temperature) and then sectioned using a diamond knife. The beam was raster scanned over the cross-sectioned paper. The spatial location of selected fragments (with certain mass to charge ratios) was then determined. In this instance the purpose was determination of the spatial distribution of the “probe” salts added to the precoat and topcoats with respect to the fragments found in the coated paper. All samples were gold coated prior to measurement to prevent charging under exposure to the ion beam ¹⁵.

3. RESULTS AND DISCUSSION

3.1 Impact of drying speed & substrate porosity

Figure 1a shows the pore volume of the precoats dried at different speeds on the basepaper (orange bars) and dried after application to a non-porous surface (green bars). It can be clearly seen that drying the coating on the non-porous surface results in a low porosity (no components from the colour have migrated and the pigment will have had time to pack the particles tightly together). After coating the same colour onto base paper the pore volume is significantly higher (orange bars). A slow drying speed increases the pore volume even higher as some binder and finer pigments are lost into the base. This is also shown by effective refractive index measurements, Figure 1b, where fast dried has a higher RI than slow dried, meaning there is less air in the surface pores (and by implication more binder and pigment).

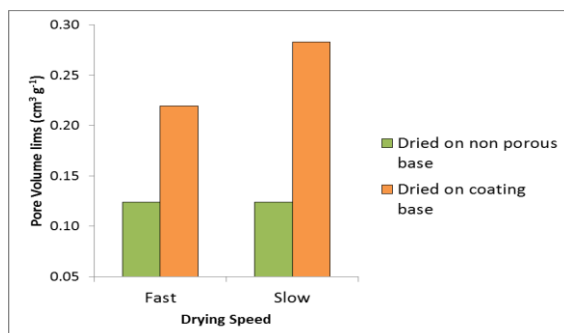


Figure 1a. Pore volume of precoat- measured on an impervious base and measured after coating onto paper and drying

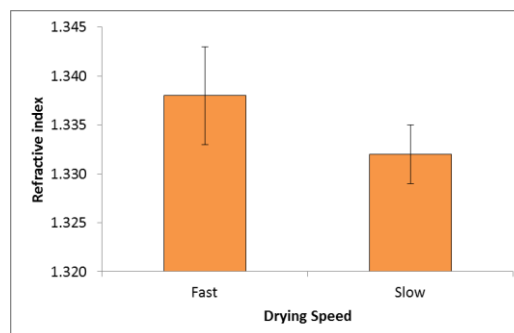


Figure 1b. Surface refractive index is higher for the fast dried coatings indicating more binder / less air is in the surface layers of the coating

Figure 2 shows the average pore size in the precoat AFTER application of the topcoat (green bars) and in the topcoat itself (orange bars). The fast dried precoat has the largest pores after topcoat application. The slow dried precoat (which had the highest porosity) has the smallest pores after topcoat application. This would indicate that the topcoat is able to slump into the precoat pores hence decreasing their size. The pore size in the topcoats is the same within error.

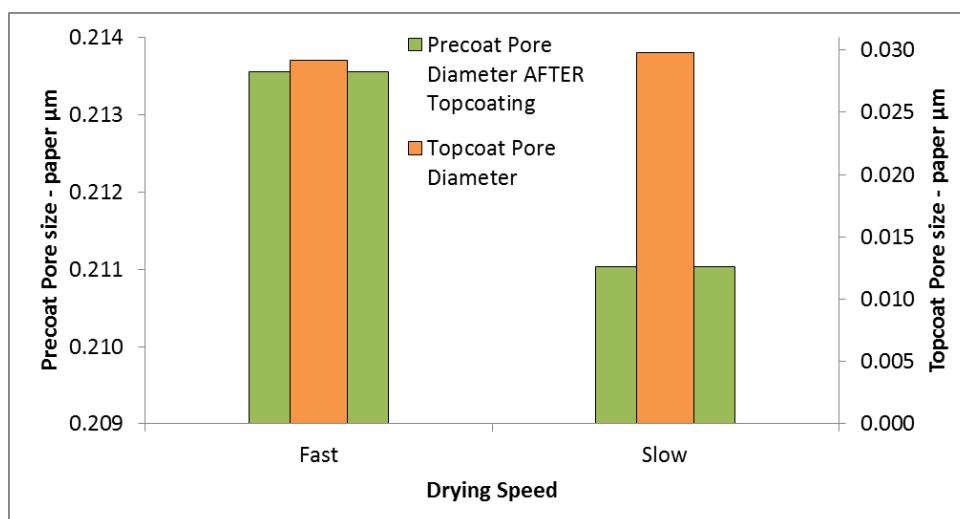


Figure 2. Pore size of the precoat after topcoat application and pore size in the topcoat.

The pore volume of the precoat AFTER the topcoat has been applied is shown in Figure 3. In the case of fast drying the precoat maintains a higher porosity than in the case of the slow drying. The porosity of the topcoats alone are similar within error. Once again this suggests that in the case of the slow drying, the topcoat fine pigments and binders have partly filled the pore structure in the precoat, thereby decreasing its porosity. Gurley permeability (Figure 4) measures the air passing through the whole paper (both coatings as well as the base). The fast dried coatings have a higher Gurley number (slower air flow and lower permeability) in both the precoat alone and after the topcoat has been applied. This may be because in the case of the fast dried precoat, there are less fine particles (pigment and latex), lost into the basepaper.

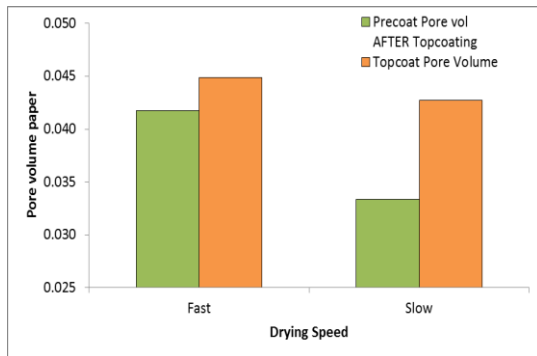


Figure 3. After topcoating has been applied - precoat pore & topcoat pore volume

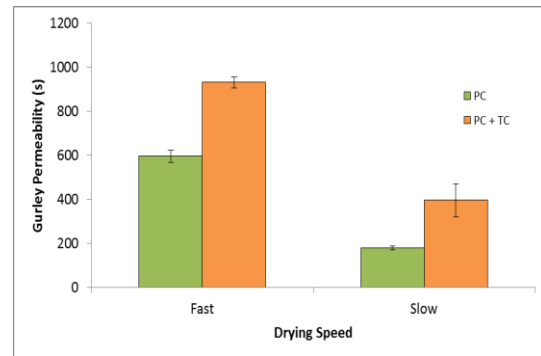


Figure 4. Gurley permeability shows the fast drying to have a lower permeability, probably due to retention of the binder and fines. This is still evident after application of the topcoat.

Another consequence of slow drying is an increase in the unevenness of the coating surface. A printed red stain (Figure 5) can be used to determine the surface porosity (the darker the stain the more porous) and the evenness of the porosity. It can clearly be seen that the slow dried coating has areas with a higher degree of unevenness than with fast drying.

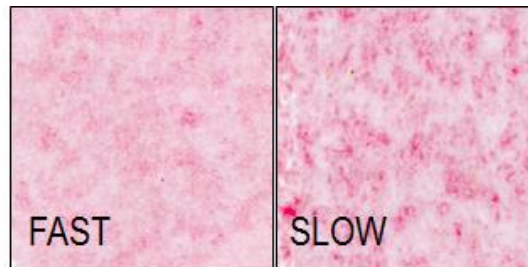


Figure 5. Unevenness in porosity caused by slower drying.

3.2 Impact of solids content & thickener on water retention

The coating solids and the use of thickener are also important in determining the final performance of the precoat and subsequent performance of the topcoat. In this section, the standard precoat was prepared at 66.5% ("high") solids and 63% ("low") solids and applied to the same basepaper. One colour containing 63% solids also had a synthetic thickener added to help retain the water and increase the low solids viscosity. Figure 6 shows the values for the GWR static dewatering of the colours.¹⁶ Decreasing the colour solids leads to more water loss. Inclusion of a thickener has a considerable impact on positively retaining the water.

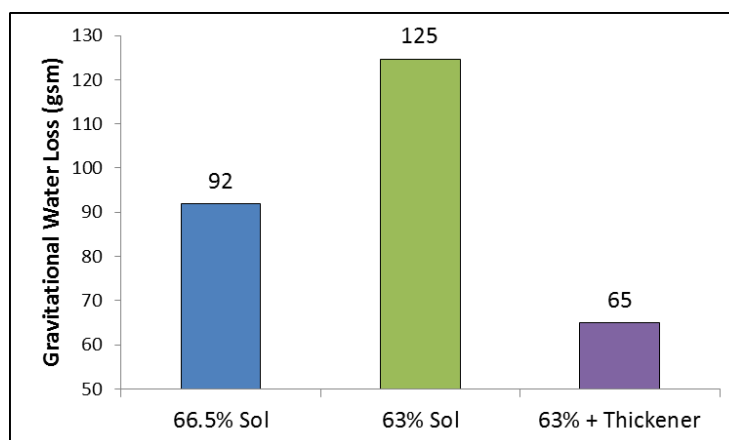


Figure 6. Lower colour solids → higher dewatering. Addition of thickener reduces this significantly

3.2.1 Changing the application solids content of the precoat

Coating at higher solids resulted in a higher binder content in the precoat and better hold out of the topcoat. The higher pigment content in the topcoat resulted in a higher brightness of the coated board (Table 2). The gloss was also greater for the higher solids content application, probably due to lower penetration of water into the base and less fibre swelling. A coating with better hold out also tends to have a higher bulk and better coverage of fibres which can also contribute to a higher gloss.

No significant strength differences with change in solids were observed in the precoat (Figure 7). In both cases the precoat was stronger than the topcoat. The topcoat strengths indicated that the lower solids precoat has a very slightly lower strength in the topcoat (possibly due to more migration of the binder from the topcoat into the precoat).

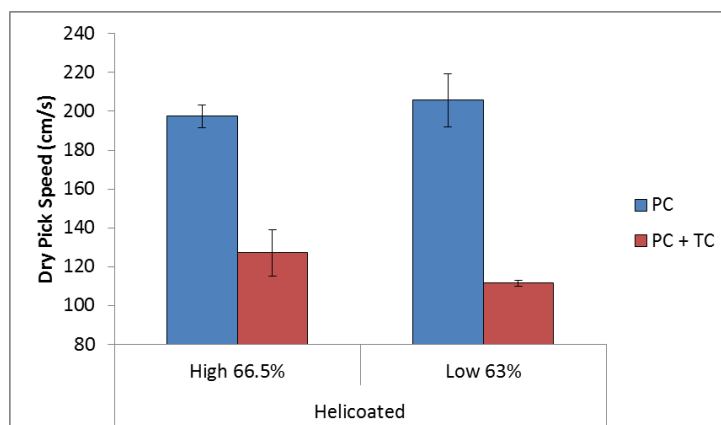


Figure 7. Dry Pick strength of precoat and topcoat

The impact of precoat colour solids on the Gurley coating permeability (Figure 8) show the higher solids having a much more closed and less permeable structure. The precoat permeability differences are also seen in the final topcoated board. The same trends are shown in the stain length results (Figure 9). A lower porosity and smoother surface will give a longer stain length. It can be seen that the highest solids coating gives a lower porosity coating both in the precoat alone and after topcoating.

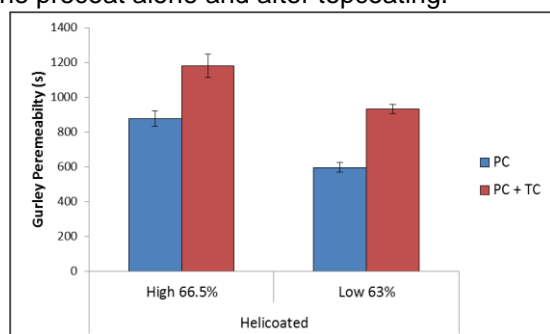


Figure 8. Higher solids colours give less permeable coatings. Differences in precoat are still observed after application of the topcoat

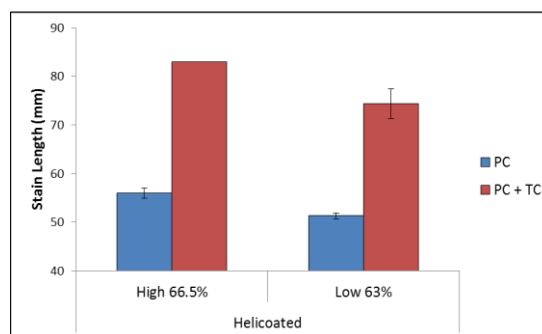


Figure 9. Stain length – longer stains are given by smoother and less porous coatings. The precoat alone and topcoated surfaces are giving longer stain lengths with higher solids

SIMS mapping of cross-sections was carried out in order to visualise the movement of water / binder from the coatings into the base fibres. Distinct markers (salts) were added to the fluid phases of both the precoat and topcoats.

Figure 10 shows cross-sections through the high solids fast drying coating applied using the Helicoater and the lower solids bench top coated sample. In both cases the colours were labelled with CsCl₂ salt in the precoat and KBr in the topcoat. Colour overlay maps of the ions are shown.

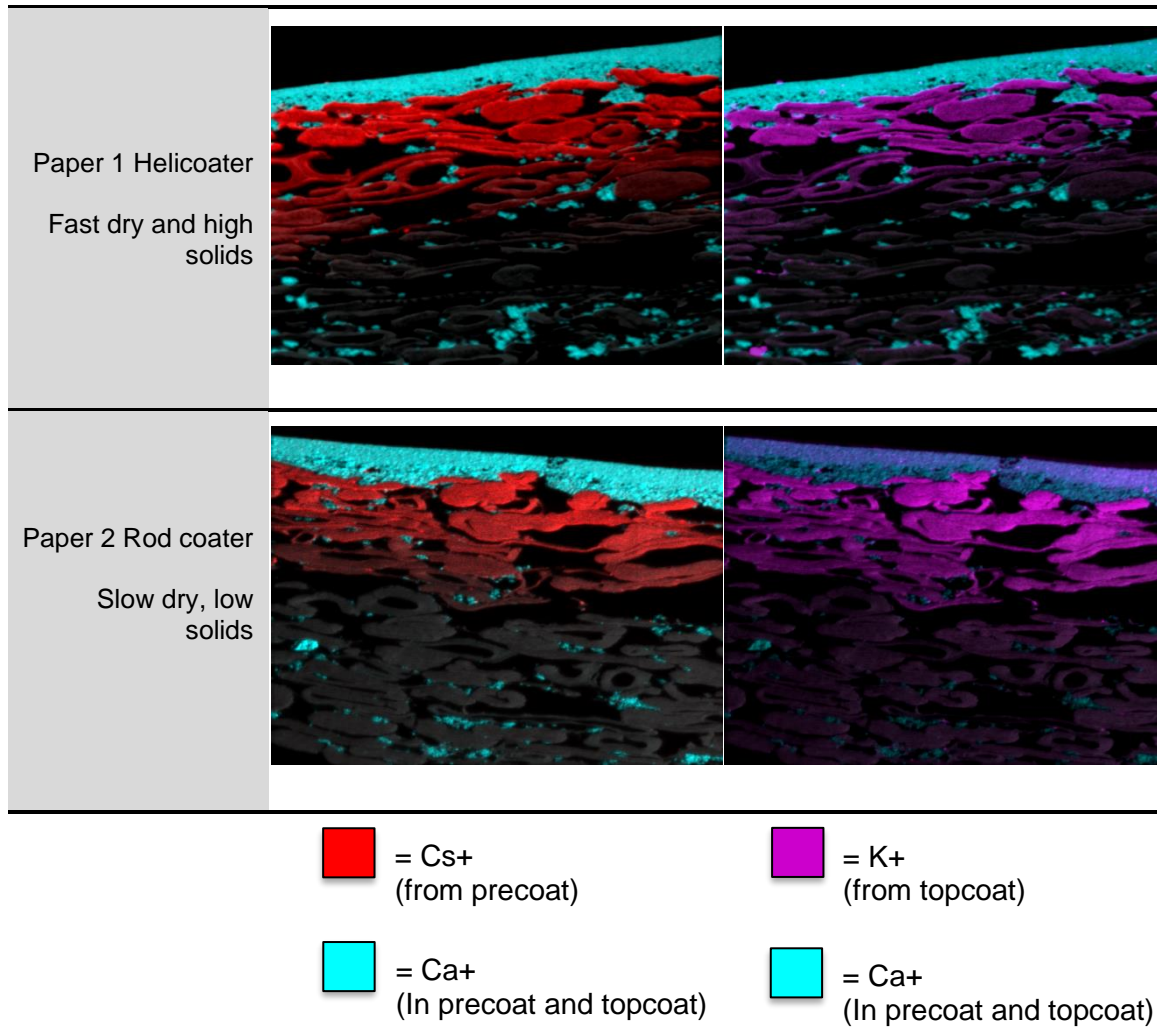


Figure 10. SIMS maps showing distribution of ions after the coatings have been dried and cross-sectioned. It is possible to determine the penetration depth of the coating fluid phase.

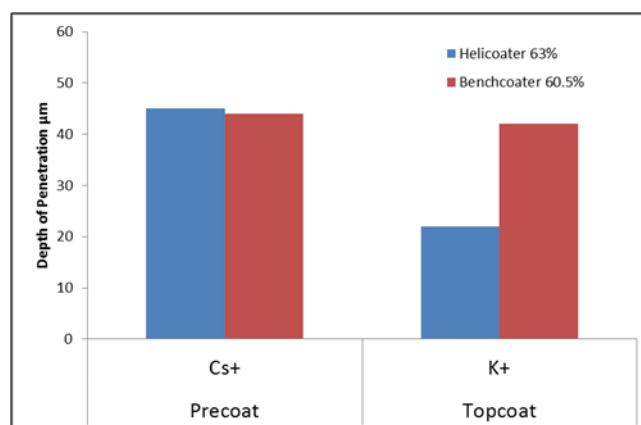


Figure 11. Depth of penetration of the fluid phase into the base for the precoat and topcoat with different solids / drying speed coating colours

It can be seen (Figure 11) that the CsCl_2 (from the Cs^+ ion map) present in the precoat has penetrated roughly the same depth into the paper in the case of the high solids Helicoating and the lower solids rod coating ($\sim 45 \mu\text{m}$ into the fibre layer). This is probably due to the easy access of the water directly from the coating into the fibres. The rate of penetration is not captured by this measurement; simply the depth to which it reaches.

However, the K^+ maps for the topcoats show differences in depth of penetration due to solids and drying regimes. In the case of the precoat which is dried more slowly and at lower solids (benchcoater 60.5%), the higher porosity has facilitated easier flow of the topcoat water through the precoat and into the base. This is therefore penetrating deeper into the fibres, than the K^+ which were in the top coat applied to the fast dried precoat. It is hypothesised that this precoat has a lower permeability / porosity and so has halted the migration of the topcoat water to some extent.

3.2.2 Impact of thickener

In order to be able to run the coating colours successfully, it is advisable to incorporate a proportion of water-retaining thickener in the colour. A proportion (0.3%) of synthetic thickener was added to the 63% coating colour and coated with fast drying on the Helicoater. The following results compare this precoat and its subsequent topcoat with a similar colour (pigment / solids / drying rate) applied without thickener. Figure 12 PPS roughness indicates that the coating with thickener is smoother, most likely due to a better retention on the surface of the basepaper.

Mercury porosimetry was used to probe the porosity of coatings applied to an impervious plastic substrate and also the basepaper, in order to emphasise differences occurring due to penetration of components into a porous basepaper.

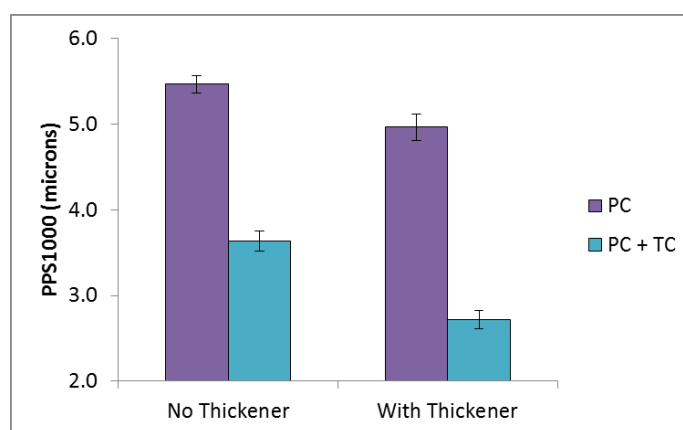


Figure 12. PPS roughness of coatings with and without thickener.

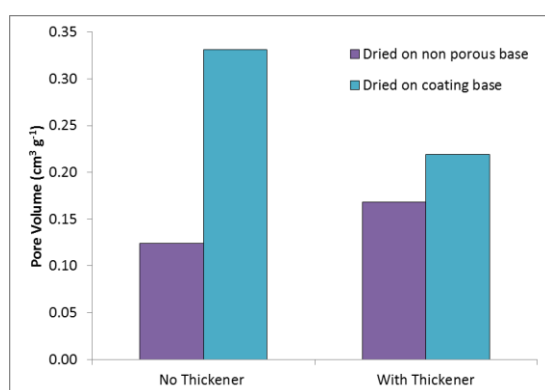


Figure 13. Mercury porosimetry impact of thickener on pore volume of precoat dried on an impervious base and coated onto basepaper

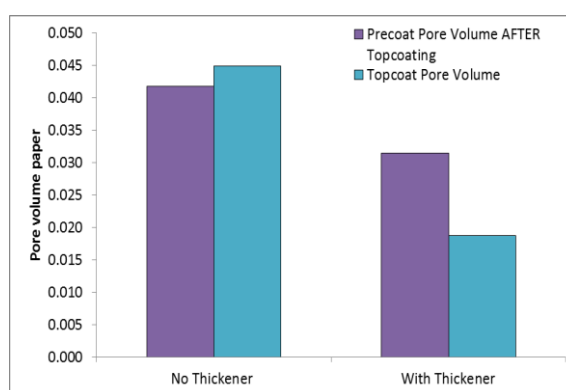


Figure 14. Mercury porosimetry impact of thickener on pore volume of precoat and topcoat coated onto basepaper

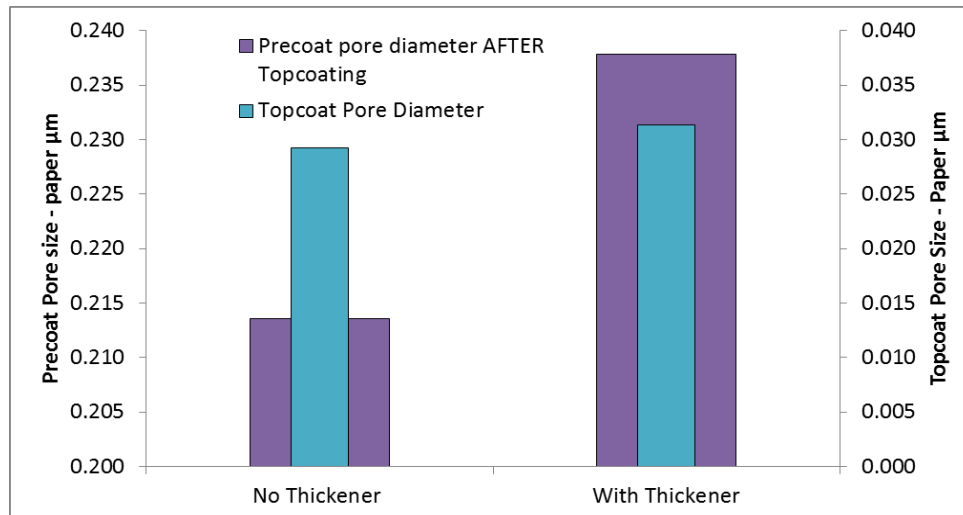


Figure 15. Mercury porosimetry impact of thickener on pore size of precoat and topcoat coated onto basepaper

When the coating is dried on a non-porous surface (purple bars) there is no opportunity for any of the binder or pigment to migrate into the base. The drying also occurs slowly and the particles have time to pack well together giving a tightly packed, low volume surface (Figure 13). When the coating layer on a basepaper is examined the pore volume is significantly higher, as some of the binder and possibly fines has migrated into the base. The thickener has a significant impact on retaining the binder in the coating layer and therefore the pore volume with the thickener is significantly lower than the one with no thickener.

The difference in the precoat porosity is also evident after the topcoat has been applied (Figure 14). When there was no thickener in the precoat, the topcoat has a higher pore volume than when the precoat contains thickener. This would indicate that the higher porosity precoat (without thickener) is absorbing some binder / fines from the topcoat. This is also indicated by the larger pore size in both the precoat and topcoat without thickener (Figure 15). The stain lengths show a more closed surface for the pre- and topcoats containing thickener (longer stain), Figure 16, and this is also observed with the higher Gurley value indicating a lower permeability, Figure 17.

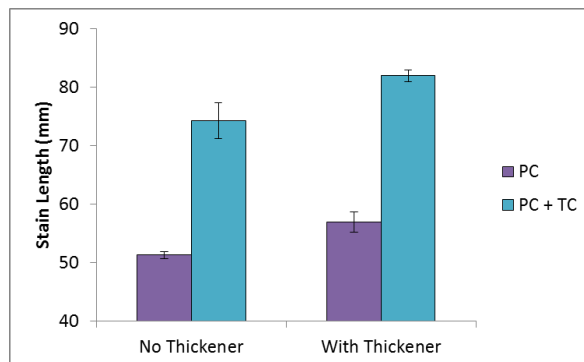


Figure 16. Impact of thickener addition in precoat to the stain length porosity of precoat and topcoat

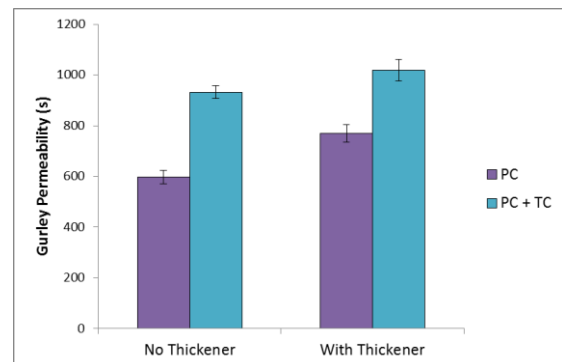


Figure 17. Impact of thickener addition in precoat to the Gurley permeability of precoat and topcoat

The properties of the boards are summarised in Table 2 for all the coating drying and solids combinations. The coating applied at the highest solids and dried the fastest has the smoothest precoat and the highest final gloss and brightness. The pick strengths are the same within error, as is the refractive index of the topcoat.

Table 2. Standard coated board properties

| | PPS1000 (μm) | (D65 - 420nm) Bness-F8 (%) | Z-T- Gloss 75° | Dry Pick (cm/s) | Stain Length (mm) | Refractive Index |
|----------------------------|------------------------------|-------------------------------------|----------------------|-----------------------|-------------------------|---------------------|
| Helicoated @ 66.5% | 4.86 | 85.1 | | 197 | 56 | |
| + TC | 3.09 | 86.6 | 53.3 | 127 | 83 | 1.339 |
| Helicoated @ 63% | 5.47 | 84.7 | | 206 | 51 | |
| + TC | 3.64 | 85.1 | 45.7 | 112 | 74 | 1.338 |
| Helicoated @ 63%+thickener | 4.96 | 85.1 | | 197 | 57 | |
| + TC | 2.72 | 85.3 | 49.6 | 130 | 82 | 1.337 |
| Rod coated @ 63% | 5.72 | 84.9 | | 207 | 51 | |
| + TC | 3.89 | 85.2 | 52.0 | 118 | 73 | 1.331 |

4. CONCLUSIONS

This work has explored the impact of solids content, drying rate and thickener content on the porosity of a precoat layer. The impact on the topcoat has then been assessed in terms of the precoat porosity. The latex and pigments remained the same throughout the study. The results have indicated that the solids content and drying rate have a very significant impact on the precoat porosity and this follows through into the topcoat and the final properties of the substrate. The basepaper porosity, roughness and surface treatment (sizing) will also impact the distribution of the precoat, however this aspect has not been studied in this work. It has been clearly shown that:

- High solids gives better hold-out.
- Fast immobilisation / drying gives better hold-out.
- Thickener can be added if required to give better hold-out.
- Topcoat follows differences in precoat.
- Surface analytical techniques such as mapping SIMS can be used to determine the depth of penetration of the fluid phase of a coating into the basepaper.

Therefore when considering the use of pigments and binders in a coating, the significant impact of the solids and drying is also a key consideration.

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